Excerpts from

A STUDY OF THE RELATIONSHIP BETWEEN SUBGRADE CALIFORNIA BEARING RATIOS AND PUMPING OF RIGID PAVEMENTS

Highway Materials Research Laboratory
Lexington, Kentucky

April, 1948

TABLE V. SUMMARY OF TRAFFIC ON NON-PUMPING ROADS AND ON THE EIGHT LIGHTEST TRAVELLED PUMPING ROADS

(Traffic Expressed as Daily Number of Axle Loads in Two Directions)

NON-PUMPING ROADS

Route No.	Roads	Over 5 T	Over 6 T	Over 7 T	Over 8 T	Over 9 T	Type Base
SR 15	Hazard-Whitesburg	51	0	0	0	0	Residual Soil
US 23	Ashland-Greenup	117	6	3	0	0	4" Crushed Rock
US 60	Grahamton-Tip Top	76	55	17	4	0	Residual Soil
SR 80	Allen-Lackey	150	39	17	9	2	Residual Soil
US 23	Prestonsburg-Pikeville	159	41	18	10	2	Residual Soil
US 60	Louisville-Middletown*	45	35	19	6	0	Residual Soil
US 68	Paducah-Benton	46	37	26	11	4	2"-6" Gravel
US 60	Henderson-Morganfield	190	139	95	38	19	Loess and Alluvium
US 51	Fulton-Clinton	235	184	102	51	10	2"-6" Gravel
US 41	Henderson-Evansville**	286	246	168	90	50	Loess and Alluvium

* Westbound.
**One Direction.

EIGHT LIGHTEST TRAVELLED PUMPING ROADS

(On the Basis of 7 Ton Axle Loads)

US 23	Paintsville-Prestonsburg	155	40	17	10	2	Residual Soil
US 60	Lexington-Winchester	96	58	24	3	0	Residual Soil#
US 42	Bedford-Carrollton	75	57	27	13	0	Residual Soil
US 42	Louisville-Bedford	84	64	30	15	0	Residual Soil
US 42	Warsaw-Carrollton	79	60	42	21	9	Residual Soil
US 27	Somerset-Burnside	91	65	42	21	0	Residual Soil#
US 31E	Louisville-Bardstown	128	97	46	23	0	Old Road Bed
US 42	Warsaw-Florence	92	70	49	24	10	Residual Soil##

\# Some sections underlain by old road bed.
\#\#Some sections underlain by glacial drift.

Approximate number and weights of axle loads that will produce pumping:

20 over 7 Tons
8 over 8 Tons

Roads over which traffic has been too light to produce pumping:

Hazard-Whitesburg .... Sample Numbers - 398, 399
Ashland-Greenup .... Sample Number - 301
Grahamton-Tip Top .... Sample Numbers - 411, 412
Allen-Lackey .... Sample Numbers - 309, 310
Prestonsburg-Pikeville .... Sample Numbers - 307, 308
Louisville-Middletown (Westbound) .... Sample Numbers - 360, 364

TABLE VI. COMPARISON OF TRAFFIC VARIATION IN KENTUCKY DURING THE PERIOD 1942-1947, AND THE APPROXIMATE DATE OF PUMPING ORIGIN

(Traffic Expressed As the Average Number of Axle Loads Weighed per 8-hour Measurement per Loadometer Station)

Axle Loads	Year					
	1942*	1943	1944	1945	1946	1947
Over 5 Ton	20	19	22	18	24	31
Over 6 Ton	12	13	15	13	13	25
Over 7 Ton	5	7	7	7	7	16
Over 8 Ton	1.1	2.6	2.6	4.2	3.6	7.7
Over 9 Ton	0.4	0.8	1.0	3.2	1.3	2.4
Over 10 Ton	0.1	0.0	0.1	0.1	0.0	0.7
Number of projects upon which pumping originated	1**	1	9	16	8	5

* No traffic records obtained for years prior to 1942.
**Pumping reported on 16 projects prior to 1942.

TABLE VII. SUMMARY OF SAMPLES ELIMINATED

No. of Samples	Reasons for Elimination	Analysis from which Eliminated	Sample Numbers
11	Traffic too light (less than 20 - seven ton and 8 - eight ton axle loads daily)	CBR Texture Soil Area	301, 307, 308, 309, 310, 360, 364, 398, 399, 411, 412
4	2-3" Base Course (Non-pumping - Not represented by sample)	CBR Texture Soil Area	216, 230, 231, 234
9	Concrete Failure (Pumping samples - Concrete disintegration, prior to pumping)	CBR Texture Soil Area	248, 249, 254, 303, 370, 390, 392, 395, 410
51*	Not Typical of Soil Area (Influenced by old road bed or bed rock excavation to the extent that 10-15% is retained on No. 10 Sieve)	Soil Area	218, 219, 233, 235, 240, 242, 243, 246, 247, 250, 259, 269, 276, 286, 292, 299, 300, 311, 312, 313, 314, 315, 319, 328, 331, 334, 337, 339, 347, 348, 352, 353, 354, 355, 362, 363, 367, 368, 369, 371, 372, 373, 375, 377, 381, 386, 387, 388, 400, 409, 413
3	Insufficient Quantity of Sample	CBR	235, 237, 298
4*	Irregular Densities for CBR (Includes samples with CBR of, or near, 15)	CBR	225, 265, 282, 356

*Includes only those not previously eliminated.

Total Samples for Texture Analysis..... 191

Total Samples for CBR Analysis......... 184

Total Samples for Soil Area Analysis... 140

TABLE VIII. SUMMARY OF THE RELATION BETWEEN THE CBR AND THE OTHER PHYSICAL PROPERTIES OF SOILS.

	PUMPING SAMPLES			
	CBR* Range	Min.	Max.	Ave.
Plastic Index	0-10	5	40	23
	10-28	4	15	8
Liquid Limits	0-5	30	65	45
	5-10	22	42	35
	10-24	22	38	30
Optimum Moisture Content	0-10	14	25	19
	10-24	13	20	16
	24- +	(One sample)		15
Maximum Density	0-10	92	120	106
	10-24	100	120	110
	24- +	(One sample)		112
Percent Swell	0-5	1	13	6
	5-10	1	8	4
	10-28	1	4	2
Specific Gravity	0-6	2.66	2.80	2.74
	6-24	2.64	2.72	2.69
	24-40	(One sample)		2.67
Percent Sand	0-5	8	55	25
	5-10	11	50	20
	10- +	4	40	15
Percent Silt	0-5	20	45	30
	5-10	24	60	40
	10- +	25	67	48
Percent Clay	0-5	25	66	50
	5-27	18	39	28

	NON-PUMPING SAMPLES			
	CBR* Range	Min.	Max.	Ave.
Plastic Index	0-10	10	30	20
	10-30	2	15	8
	30-40	2	8	6
Liquid Limits	0-5	32	60	43
	5-10	30	45	37
	10-50	20	35	28
Optimum Moisture Content	0-10	15	24	20
	10-24	12	22	17
	24-40	11	16	14
Maximum Density	0-10	96	116	106
	10-24	100	120	110
	24-48	108	122	115
Percent Swell	0-10	1	7	3
	10-25	1	5	2.5
	25-40	1	3	2
Specific Gravity	0-6	2.66	2.76	2.72
	6-24	2.64	2.72	2.67
	24-40	2.64	2.70	2.66
Percent Sand	0-5	5	25	14
	5-10	2	32	13
	10-25	4	70	18
	25- +	30	80	52
Percent Silt	0-5	20	50	37
	5-10	32	55	45
	10-30	20	75	50
Percent Clay	0-5	28	60	45
	5-10	28	40	32
	10-25	16	38	27
	25-50	8	23	16

*CBR as obtained by Testing Laboratory Method.

TABLE IX. RESEARCH LABORATORY CBR CHECK TESTS ON DUPLICATE SAMPLES

		SAMPLE NUMBERS									
		245	254	256	261	265	311	329	343	365	397
CBR	Test 1	4	27	5	21	16	22	19	13	15	31
	Test 2	4	30	5	19	14	30	12	15	15	17
CBR MOISTURE CONTENT (Entire Sample After Soaking)	Test 1	22	17	19	17	18	10	12	15	15	12
	Test 2	19	21	16	16	22	11	13	14	15	13
CBR DRY DENSITY (After Soaking)	Test 1	108	112	112	115	113	137	125	120	116	122
	Test 2	110	108	117	112	113	130	121	121	119	122
PER CENT VOLUME CHANGE	Test 1	3.4	2.3	5.4	2.6	5.5	1.5	1.9	3.6	5.8	2.7
	Test 2	5.5	2.4	7.0	2.9	3.7	2.4	3.9	4.3	4.0	4.1
SOAKING PERIOD	Test 1	6	6	10	4	6	6	6	12	6	7
	Test 2	8	8	8	8	8	8	10	10	10	10

TABLE X. SUMMARY OF CBR RESULTS ON TRIPLICATE SAMPLES

	SAMPLE NUMBERS									
	313	320	329	343	360	365	382	397	405	406
CBR										
Testing Laboratory - Frankfort	2	25	9	7	14	7	6	37	8	7
PRA Laboratory - Washington	3	25	15	10	11	9	7	41	17	9
Research Laboratory - Lexington	1	22	12*	13	13	15*	7	31	19	10
CBR MOISTURE CONTENT (Total Sample-After Soaking)										
Testing Laboratory - Frankfort	-	-	-	-	-	-	-	-	-	-
PRA Laboratory - Washington	25	12	13	16	21	17	16	13	18	20
Research Laboratory - Lexington	26	12	13*	15	18	16*	16	12	17	19
CBR DENSITY (After Soaking)										
Testing Laboratory - Frankfort	105	126	125	122	119	120	124	130	114	113
PRA Laboratory - Washington	101	124	122	118	115	116	117	124	112	115
Research Laboratory - Lexington	98	125	121*	120	114	119*	116	123	113	109
CBR SOAKING PERIOD (Days)										
Testing Laboratory - Frankfort	-	-	-	-	-	-	-	-	-	-
PRA Laboratory - Washington	10	6	4	6	8	6	8	4	7	7
Research Laboratory - Lexington	6	6	10*	12	6	10*	7	7	7	8
PER CENT VOLUME CHANGE										
Testing Laboratory - Frankfort	3.8	1.0	1.5	2.5	1.2	4.8	3.8	1.4	2.0	3.4
PRA Laboratory - Washington	4.1	0.4	2.2	3.3	2.4	1.5	1.9	2.8	2.5	3.2
Research Laboratory - Lexington	1.4	2.1	3.8*	3.6	2.1	4.0*	7.5	2.7	2.5	2.6

* Results of second test - duplicate sample - at Research Laboratory in Lexington.

NOTE: All samples except 360 and 382 were prepared for the CBR test (including Moisture-Density Relation) by the Research Laboratory in Lexington. Samples 360 and 382 were prepared independently by each of the laboratories.

TABLE XI. LIST OF SAMPLES THAT DID NOT HAVE REQUIRED AMOUNT OF 3/8" TO NO. 4 MATERIAL ADDED FOR CBR TEST

*Sample Number	Per Cent of 3/8" to No. 4 Material Required	Per Cent of 3/8" to No. 4 Material Used	Pumping	CBR	REMARKS
240	56	27	No	39	Disregard
243	47	15	Yes	4	Questionable
259	29	21	No	34	Disregard
274	14	7	Yes	3	Disregard
281	13	6	Yes	2	Disregard
292	21	9	No	8	Questionable
295	27	6	Yes	5	Questionable
315	46	32	Yes	2	Disregard
317	20	9	Yes	2	Disregard
319	32	16	Yes	4	Questionable
326	18	5	Yes	19	Disregard
334	32	19	Yes	2	Disregard
337	32	20	No	27	Disregard
344	16	7	No	7	Questionable
347	49	20	Yes	67	Disregard
348	43	36	No	78	Disregard
350	8	2	Yes	2	Disregard
352	37	4	No	3	Questionable
353	40	24	Yes	7	Questionable
354	29	9	Yes	2	Questionable
355	36	14	Yes	1	Questionable
361	16	4	Yes	20	Disregard
362	61	38	No	67	Disregard
363	40	22	No	42	Disregard
367	60	19	No	47	Disregard
368	55	42	No	90	Disregard
369	54	37	No	94	Disregard
371	47	23	No	42	Disregard
373	24	11	Yes	3	Questionable
374	10	4	No	6	Disregard
375	25	9	Yes	5	Questionable
377	27	7	Yes	9	Questionable
381	20	0	No	21	Disregard
383	12	3	No	5	Disregard
385	7	1	Yes	3	Disregard
386	40	18	Yes	38	Disregard
388	35	7	No	21	Disregard
391	16	6	Yes	5	Questionable
393	42	13	Yes	7	Questionable
394	16	4	Yes	9	Disregard
409	44	36	No	76	Disregard
413	9	1	Yes	2	Disregard
416	20	2	Yes	6	Questionable

* Includes only those samples not eliminated due to Concrete Failure, Low Traffic, Base Course, or CBR Density. (See Table VII.)

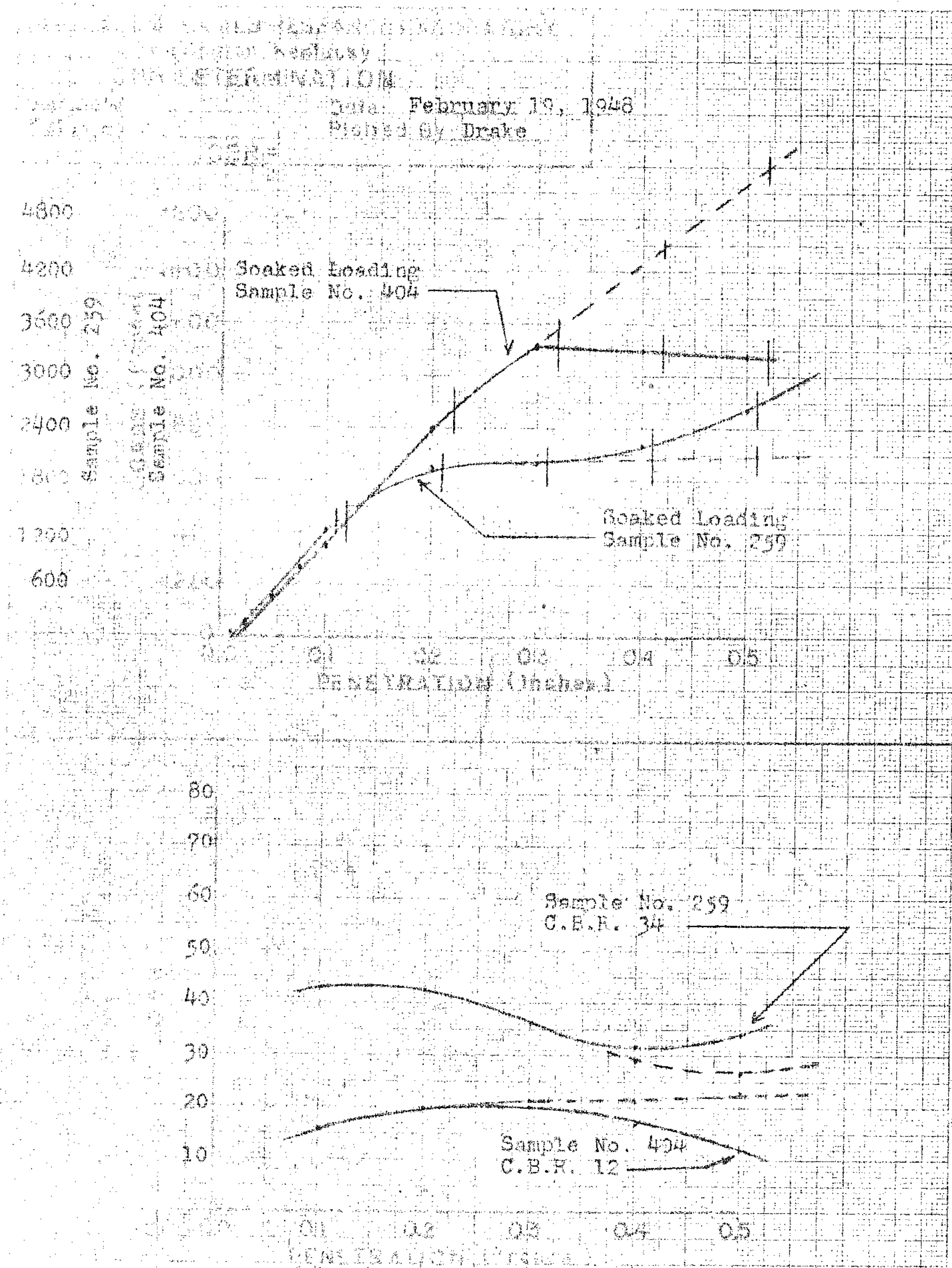


Fig. 9

Chart 3-5, May 1947

2. CBR VERSUS PUMPING

The CBR value as a measure of the strength characteristic of soil with regard to pumping was investigated from two considerations. The first was on the basis of the only CBR criterion thus far advanced, which can be summarized as follows:

1. For CBR values equal to or greater than 15, the soil will not pump.
2. For CBR values of 10 to 14, inclusive, the soil will pump if the sum of the plasticity index and the per cent clay is equal to or greater than 45.
3. For CBR values of 8 and 9, the soil will pump if the sum of the plasticity index and the per cent clay is equal to or greater than 40.
4. For CBR values equal to or less than 7, the soil will pump.

Since this criterion was based on interpretation of "trends" in CBR test data (as described previously in that section of the report), the test results obtained in this study were scrutinized from that standpoint. Later, evaluation was made also on the basis of absolute CBR values at various penetrations regardless of trends. This led to the second consideration or final analysis of all data without regard to any established criterion in an effort to determine what differentiation of CBR data would provide the greatest degree of accuracy in predicting pumping as it was actually found at locations represented by these samples.

The percentage accuracy of the criterion stated above including evaluation of CBR data by trends is calculated in Table XIII. At the beginning of the table, the percentage accuracy is calculated using all 212 samples. Then progressing

TABLE XIII. CBR ANALYSIS BASED ON TESTING LABORATORY THEORY

	Range of CBR					
		8 - 9, Inclusive		10 - 14, Inclusive		
	15 or Greater	P.I. + Clay 40 or Greater	P.I. + Clay Less Than 40	P.I. + Clay 45 or Greater	P.I. + Clay Less Than 45	7 or Less
Number of Samples*	78	9	1	11	18	95
Number of Non-Pumping Samples	59	3	1	7	11	27
Number of Pumping Samples	19	6	0	4	7	68
Per Cent Accuracy*	76	67	100	37	61	72
Number of Pumping Samples Eliminated Due to Concrete Failure	2	1	0	0	0	6
Number of Non-Pumping Samples Eliminated Due to Light Traffic*	3	1	0	1	2	4
Number of Non-Pumping Samples Eliminated Due to Base Course*	3	0	0	~~0~~ 1	~~1~~ 0	0
Number of Samples Eliminated Due to Irregular Density*	~~2P~~ 2NP	0	0	0	0	0
Number of Samples After Elimination	66	7	1	~~10~~ 9	~~15~~ 16	85
Number of Non-Pumping Samples After Elimination	51	2	1	~~6~~ 5	~~8~~ 9	23
Number of Pumping Samples After Elimination	15	5	0	4	7	62
Final Per Cent Accuracy	77	71	100	40	53	73

*For Samples Eliminated See Table VII.

Preliminary:
Total Number of Samples = 212
Number Accurate = 149
Per Cent Accuracy = 70%

Final:
Total Number of Samples = 184
Number Accurate = ~~131~~ 132
Per Cent Accuracy = 72%

For CBR's Between 8 and 14, Inclusive:
Number of Samples = 33
Number Accurate = ~~18~~ 19
Per Cent Accuracy = 55% 58%

TABLE XIV. CBR ANALYSIS BASED ON RESEARCH LABORATORY INVESTIGATION.

Limits: Group A. If maximum CBR value is 5 or less, soil will pump if traffic is over 20-7 ton axles daily.

Group B. If maximum CBR is between 6 and 10, inclusive, soil will pump under traffic over 100-7 ton axles daily.

Group C. If maximum CBR is over 11, minimum is less than 17, soil will pump under traffic over 200-7 ton axles daily.

Group D. If minimum CBR value is 17 or greater, soil will not pump under traffic up to 275-7 ton axles daily.

	Group A	Group B	Group C	Group D
No. of Samples	65	37	77	33
No. Accurate	51	22	41	30
No. Inaccurate	14	15	36	3
Percent Accuracy	78	60	53	91
No. of Samples After Elimination*	59	33	66	30
No. Accurate After Elimination*	47	21	41	28
No. Inaccurate After Elimination	12	12	25	2
Percent Accuracy	80	64	62	93

Preliminary-Overall Accuracy:
No. of Samples = 212**
No. Accurate = 144
Percent Accuracy= 68

Final-Overall Accuracy:
No. of Samples = 188
No. Accurate = 137
Percent Accuracy = 73

*For Samples Eliminated See Table VII.

**Samples 225, 265, 282, and 356 included in this Analysis.

TABLE XV. TEXTURE ANALYSIS

Range of Per Cent Sand and Gravel (Inclusive)

	71 to 100	66 to 100	61 to 100	56 to 100	51 to 100	46 to 100	41 to 100	0 to 30	0 to 35	0 to 40	0 to 45	0 to 50	0 to 55	0 to 60
Total Samples	11	19	25	35	45	54	62	124	140	153	161	170	180	190
Total Pumping Samples	0	3	5	7	13	17	22	67	76	84	89	93	99	101
Total Non-Pumping Samples	11	16	20	28	32	37	40	57	64	69	72	77	81	89
Per Cent Accuracy	100	85	80	80	71	69	65	54	54	55	55	55	56	54
Total Pumping Samples Eliminated (Concrete Failure)	0	1	1	1	4	4	5	3	3	4	5	5	8	8
Total Non-Pumping Samples Eliminated (Traffic)	0	1	3	4	5	6	6	1	3	5	5	6	7	8
Total Samples Eliminated Due To Base Course	0	0	0	0	0	0	0	4	4	4	4	4	4	4
Final Total Number of Samples	11	17	21	30	36	44	51	116	130	140	147	155	161	170
Final Total Number of Pumping Samples	0	2	4	6	9	13	17	64	73	80	84	88	91	93
Final Total Number of Non-Pumping Samples	11	15	17	24	27	31	34	52	57	60	63	67	70	77
Final Per Cent Accuracy	100	88	81	80	75	71	67	55	56	57	57	57	57	55

Overall Accuracy for Criteria Requiring More Than 55% Sand and Gravel -

Preliminary:

Total Samples = 215
Correct Samples = 128
Per Cent Accuracy = 60%

Final:

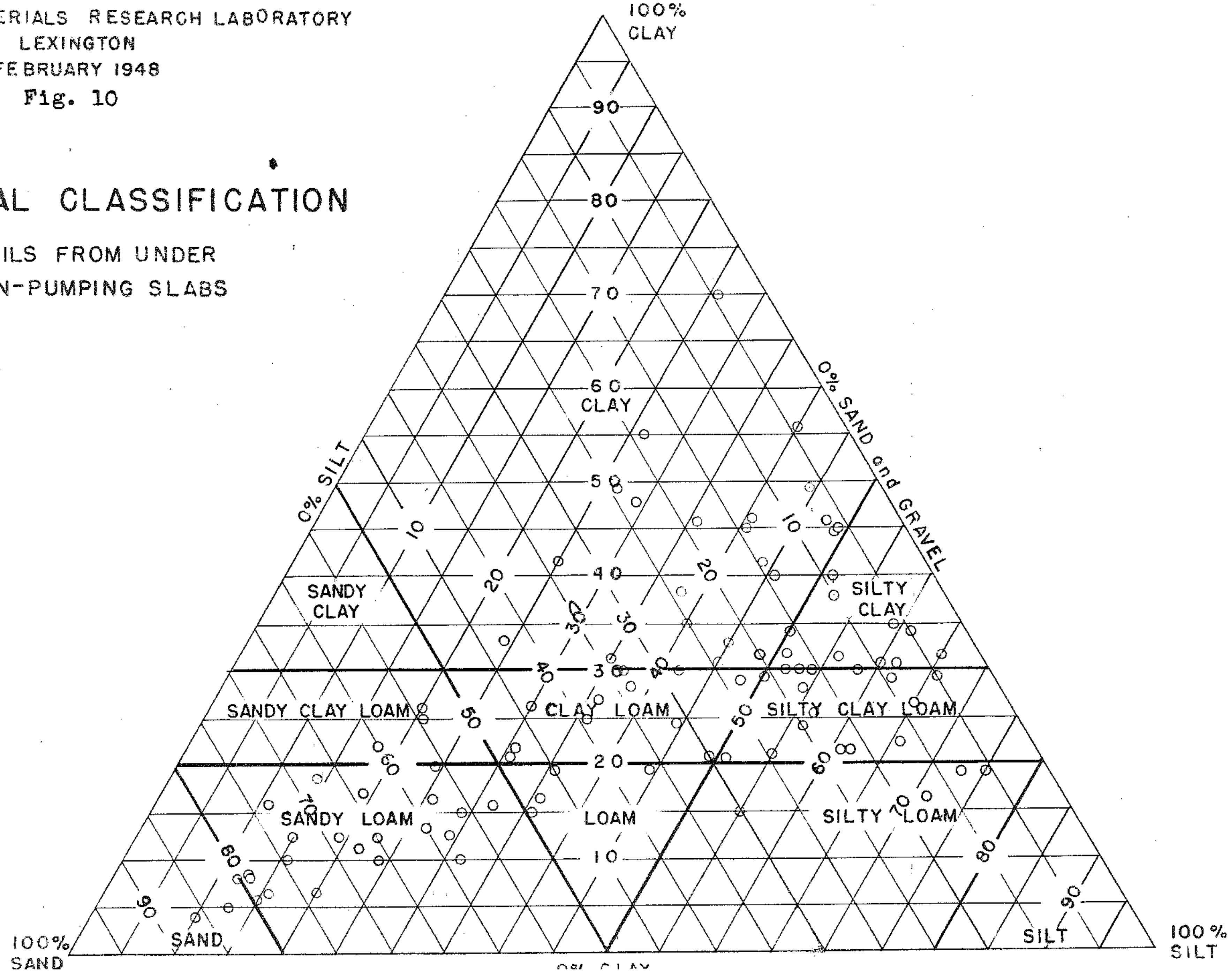
Total Samples = 191
Correct Samples = 115
Per Cent Accuracy = 115/191 = 60%

KENTUCKY DEPARTMENT of HIGHWAYS
HIGHWAY MATERIALS RESEARCH LABORATORY
LEXINGTON
FEBRUARY 1948

Fig. 10

TEXTURAL CLASSIFICATION

SOILS FROM UNDER
NON-PUMPING SLABS



KENTUCKY DEPARTMENT of HIGHWAYS
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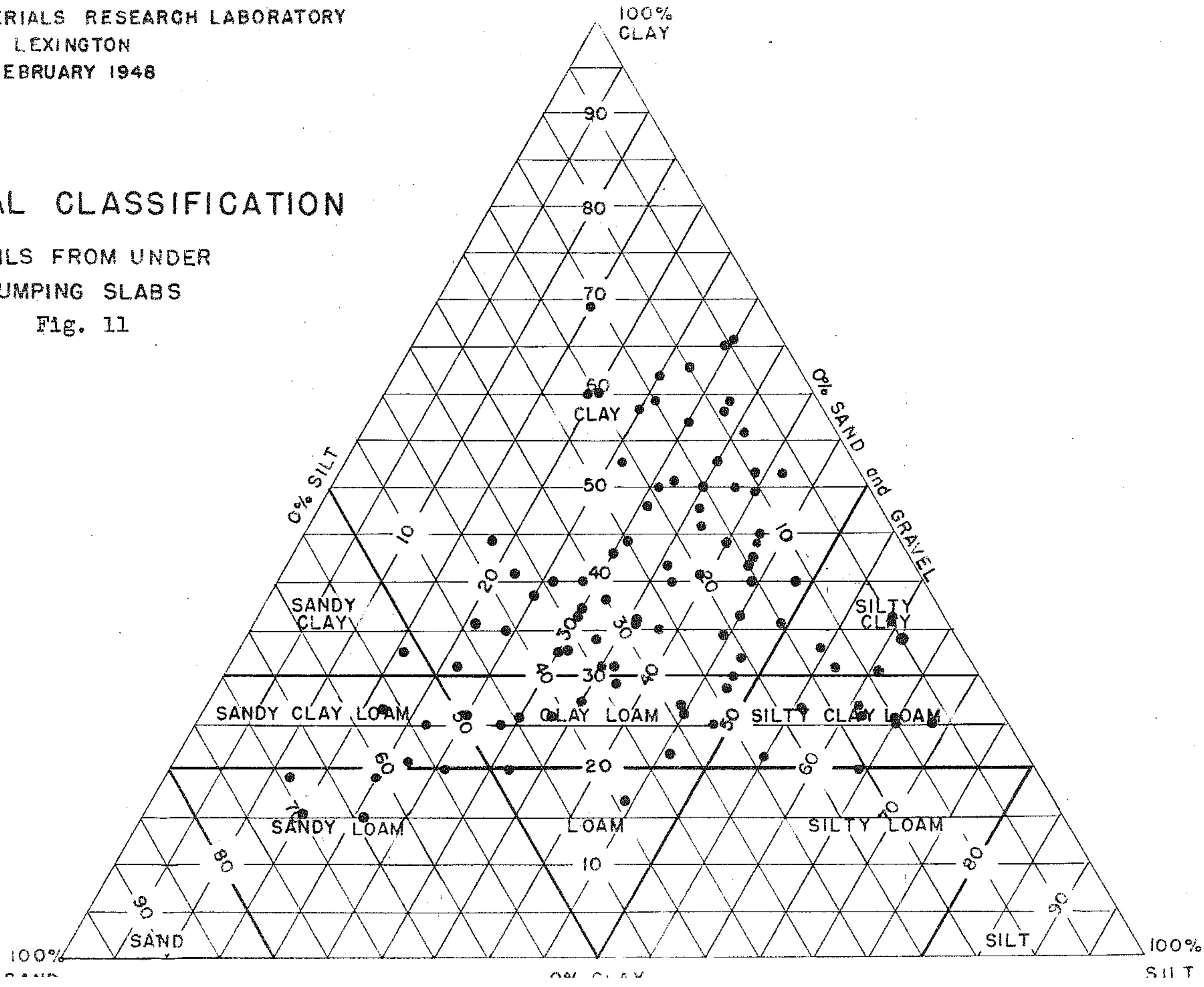
LEXINGTON
FEBRUARY 1948

TEXTURAL CLASSIFICATION

SOILS FROM UNDER
PUMPING SLABS
Fig. 11



textural classification groups were combined in the most advantageous ways as reflected by the over-all per cent accuracy for predicting pumping and non-pumping. After application of traffic data to the various groups the following criterion showed an over-all percentage accuracy of 70.

Group I - Soils containing less than 20 per cent clay will not pump for traffic up to 250 seven-ton axle loads daily.

Group II- Soils containing 20 per cent or greater clay content and 50 per cent or greater silt content will not pump for traffic up to 200 seven-ton axle loads daily.

Group III- Soils containing 20 per cent or greater clay content and less than 50 per cent silt content will pump for traffic in excess of 30 seven-ton axle loads daily.

For Group I, the accuracy was 26 of 36 samples (86 per cent); for Group II, 25 of 39 samples (61 per cent); and Group III, 78 of 116 samples (68 per cent).

For the sake of comparison with conditions in other states, the data from Fig. 2 in North Carolina (8), Fig. 8 in the Kansas (4), Fig. 5 in the Tennessee (2), and Fig. 12 in the Illinois reports were checked against this criterion. The over-all percentage accuracy was 68 on a basis of 391 samples taken in those four states. For Group I, the accuracy was 89 per cent; Group II, 71 per cent; and Group III, 54 per cent. The combined per cent accuracy for Groups I and II was 85, and this is on a basis of169 of the 391 total samples. By including the data from Kentucky with those from the four other states, the combined accuracy for Group I and II is 84, on a basis of 239 samples out of 582. It was also noted that of

TABLE XVII. SUMMARY OF THE NUMBER OF SAMPLES USED IN THE GEOLOGIC AREA ANALYSIS

Geologic Area	Number of Samples Eliminated		Total Samples After Elimination	
	Pumping	Non-Pumping	Pumping	Non-Pumping
Alluvium	1	1	1	16
Glacial	None	2	9	11
Loess	2	8	9	10
Pennsylvanian				
Dixon (Conemaugh)	None	None	1	0
Undifferentiated Pottsville	3	12	9	9
Mississippian				
Leitchfield (Chester)	None	1	3	1
Bethel Ss. (Chester)	1	1	0	1
Mammoth Cave Ls. (Meramec)	None	1	1	1
O'Hara Ls. (Meramec)	1	2	0	1
Fredonia Ls. (Meramec)	None	None	0	2
St. Louis Ls. (Meramec)	1	1	8	2
Undifferentiated Meramec	1	None	4	0
Undifferentiated Osage	2	1	2	1
Devonian				
Undifferentiated	None	3	1	1
Silurian				
Louisville Ls.	2	3	2	1
Undifferentiated	4	None	3	0
Ordovician				
Richmond	4	None	4	2
Maysville	6	3	2	0
Eden	2	1	9	0
Cynthiana	1	2	5	0
Trenton	None	2	3	5

OGIC AREA

	iles of umping avement	Miles of Non-Pumping Pavement	Lightest* Traffic that Produced Pumping		Heaviest* Traffic That Did Not Produce Pumping	
			Over 7 Ton	Over 8 Ton	Over 7 Ton	Over 8 Ton
Alluvium	2.4	45.6	42	21	168	90
Glacial	22.4	40.6	30	15	78	52
Loess	10.8	69.3	203	120	235	139
Dixon (Cons	0.5***	0.0	235	139	--	--
Pottsville (	11.3	65.6	17	10	212	109
Leitchfield	3.3	8.5	235	139	212	109
Bethel Ss. (	0.2	0.5	78	52	17	4
Mammoth Cav	2.2	2.9	156	68	156	68
O'Hara Ls. (	0.1	11.9	--	--	212	109
Fredonia Ls.	0.4	4.5	--	--	275	165
St. Louis L	25.5	19.5	52	35	275	165
Meramec (Mi	3.7	9.2	118	79	--	--
Osage (Miss.	3.0	4.9	42	21	109	47
Devonian (U	2.9***	20.2	30	15	30	15
Louisville	2.7	10.1	58	16	30	15
Silurian (U	3.2***	18.1	30	15	--	--
Richmond (O	15.0***	2.9	27	13	161	70
Maysville (	20.1***	5.0	27	13	--	--
Eden (Ordov	29.6	1.8	27	13	--	--
Cynthiana (	10.8	15.8	24	3	--	--
Trenton	1.5	25.9	78	44	244	144

regarding the best type other than what may be implied from the data and criteria concerning subgrades.

H. Summary

The following is a brief summary of the analysis:

1. Comparisons were made of the various criteria for predicting pumping or non-pumping. The basis for the comparison was the number of samples for which the criteria was valid, expressed as a per cent of the total number of samples. (p. 13)
2. The number and weight of axle loads in excess of seven tons appeared to have been responsible for producing the greatest amount of pumping. For adverse conditions of soil and moisture and for traffic in two directions 20 axles over seven-ton, daily, will produce pumping. (p. 15)
3. Samples were eliminated from the analysis if: (1) the sample was from a project for which the traffic was lower than 20 seven-ton axle loads daily; (2) the sample represented the soil <u>under</u> a base course (for non-pumping situations only); and (3) the sample was taken from beneath a badly disintegrated section of concrete where the failure was undoubtedly due to expansion, contraction, or durability characteristics of the concrete. (p. 16)
4. In general, the CBR value may be duplicated for low values (10 or below). However for CBR's over ten, discrepancies of one to three points are to be anticipated. (p. 18)

5. Incidental, in other than a general consideration of soil data, was the fact that the CBR value using the specified procedure is generally high for:
   a. Soils with low values of liquid limit, plasticity index, optimum moisture content, per cent swell, specific gravity, and per cent clay. (p. 17)
   b. Soils with high values for maximum density (standard Proctor Test), per cent silt, and per cent sand and gravel (retained on No. 270 sieve). (p. 17)
6. Compliance with the CBR procedure, with regard to use of material retained on the No. 4 sieve, was not always followed due to insufficient quantity of material passing the 3/8 inch sieve and retained on the No. 4. In such cases, only the amount of material available was used, in order to avoid introducing the variables of grain shape and type of material. No measurement was made of the effect of adding only a portion of the required amount. (p. 19)
7. In interpreting the CBR versus Penetration curve, the CBR values at <u>all</u> penetrations were considered important in analyzing the relationship between the CBR and pumping. The "absolute" value of the curve was preferred to the "trend". No effect was noted on the accuracy in predicting pumping, when CBR values obtained by the "trend" method were substituted for the

"absolute" value. (p.21)

8. The moisture content of the entire CBR sample even after the prolonged soaking period specified was, on the average, lower than either the field moisture content or the plastic limit of the soil. In approximately one-fourth the cases, the CBR moisture content was within two per cent of the plastic limit. The field moisture contents were approximately equally divided above and below the plastic limit. Approximately one-third were within 2 per cent of the plastic limit. (p. 25)

9. The CBR test compaction resulted in higher densities than either the field situation, or the maximum density as obtained by the standard Proctor Test. (p. 25)

10. The over-all percentage accuracy of the following CBR theory for predicting pumping was 72 per cent. For CBR values of 15 or greater, the accuracy was 77 per cent; for those between 8 and 14, inclusive, 55 per cent; and for those 7 or lower, 73 per cent. (p. 26)

    a. For CBR values equal to or greater than 15, the soil will not pump.

    b. For CBR values of 10 to 14, inclusive, the soil will pump if the sum of the plasticity index and the per cent clay is equal to or greater than 45.

    c. For CBR values of 8 and 9, the soil will pump if the sum of the plasticity index and the per cent clay is equal to or greater than 40.

    d. For CBR values equal to or less than 7, the soil will pump.

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11. On the basis of the following CBR theory, the overall accuracy was 73 per cent. For Group A, the accuracy was 80 per cent; Group B, 64 per cent; Group C, 62 per cent; and Group D, 93 per cent. The maximum and minimum CBR values in the theory refer to the highest and lowest values, respectively, of the absolute CBR versus Penetration Curve. (p. 27)

Group A. If the maximum CBR value is 5 or lower, the soil will pump if the traffic is greater than 20 seven-ton axle loads daily.

Group B. If the maximum CBR value is between 6 and 10, inclusive, the soil will pump if the traffic is greater than 100 seven-ton axle loads daily.

Group C. If the maximum CBR value is 11 or greater, and the minimum CBR value is 16 or lower, the soil will pump if the traffic is greater than 200 seven-ton axle loads daily.

Group D. If the minimum CBR value is 17 or greater, the soil will not pump for traffic up to 275 seven-ton axle loads daily.

12. No dependable relationship was found between pumping and optimum moisture content and maximum density (standard Proctor Test), per cent swell (CBR), sand and gravel content, silt content, clay content, or the silt / clay ratio. There appeared to be a trend of the soils with low plasticity indexes and low liquid limits to resist pumping.

13. Higher degrees of moisture in the pumping locations indicated that poor surface drainage had some effect on the performance of a soil or soil area, with

regard to pumping. (p. 31)

14. On the average, the relative densities of the CBR samples for the pumping locations were lower than those for the non-pumping locations, and the relative field densities of the pumping locations, on the average, were slightly higher than those of the non-pumping locations. (p. 32)

15. The textural classification theory stating that soils with more than 55 per cent retained on the No. 270 sieve (.05 mm.) will not pump, showed an over-all accuracy of 60 per cent. Twenty-four samples of 30 with more than 55 per cent retained were not pumping, while 91 of 161 with less than this amount of granular material were pumping. The critical value for traffic on the granular group was 250 seven-ton axle loads daily (no greater traffic encountered), and ranged from 20 to 100 seven-ton axle loads daily for the fine grained soil group. (p. 33)

16. Statistical analyses of the gradation curves for the samples with more than 55 per cent sand and gravel indicated that wide ranges in grain sizes resulted in large "sorting" values. Five of the six pumping samples had larger "sorting" values than 19 of the 24 non-pumping samples. (p. 35) The relatively poor performance of this type material with regard to pumping is undoubtedly

due to a segregation of the larger from the finer material. This segregation could have taken place at the time of construction, or it could have been the result of repeated heavy loads. In either case, the material left at subgrade level would have a comparatively high clay content.

17. The following textural classification criterion for predicting pumping and non-pumping was developed from typical triangular charts upon which the results of the Mechanical Analysis had been plotted:

Group I - Soils containing less than 20 per cent clay will not pump for traffic up to 250 seven-ton axle loads daily.

Group II - Soils containing 20 per cent or greater clay content and 50 per cent or greater silt content will not pump for traffic up to 200 seven-ton axle loads daily.

Group III - Soils containing 20 per cent or greater clay content and less than 50 per cent silt content will pump for traffic in excess of 30 seven-ton axle loads daily.

The over-all accuracy of the criterion was 70 per cent, and for the individual groups: Group I, 86 per cent; Group II, 61 per cent; and Group III, 68 per cent. The criterion, neglecting traffic, was applied to the other textural data from the reports on pumping from North Carolina, Kansas, Tennessee, and Illinois. The over-all accuracy was 68 per cent, and for the individual groups were: Group I, 89 per cent; Group II, 71 per cent; and Group III, 54 per cent. The comparison for this textural classification criterion indicated that soils having low clay contents and/or high silt contents are above average in resistance to pumping. (p. 37)

18. The range of results of the physical tests, and the mileage of pumping and non-pumping in each soil area indicated in general, that the performance of residual soils with respect to pumping was poorer than the performance of soils that have been transported. Notable exceptions were the soils derived from the Pottsville (Pennsylvanian) and Trenton (Ordovician) geologic groups of formations. Particularly poor performances were noticeable from the soils derived from the following groups of geologic formations: Leichfield (Pennsylvanian), St. Louis and undifferentiated Meramec of the Mississippian, the Silurian, ~~the Devonian~~, and Richmond, Maysville, Eden and Cynthiana of the Ordovician. (p. 38)

19. No significant difference could be attached to the presence or absence of expansion joints, contraction joints, mesh reinforcement, or marginal reinforcement. However, design and construction features were not given primary consideration in the investigation. (p. 41)

20. Traffic-bound surfaces appeared to give better than average service when left at subgrade level. (p. 43)

21. In general, the data as a whole showed that pavements in cuts are more vulnerable to pumping than pavements in fills. The comparison of samples from fill sections alone showed an over-all per cent accuracy of

80 per cent for the CBR criterion of paragraph 11, above, while those from cut sections showed an over-all percentage accuracy of 66 per cent. These figures, combined with field and laboratory data of Annexes 2 and 5, indicate rather conclusively a difference in field conditions at cuts versus fills that cannot be reflected solely by results of laboratory tests. (p. 44)

22. Since age and quality of concrete varied widely, the severity of pumping was based on miles of pumping pavement versus miles of non-pumping pavement. (p. 46)

23. It is recognized that traffic will increase both in volume and in weight of axle loads. What the effect this increase will have in any criterion based on present traffic is problematical. (p. 46)

24. On several projects excavation through rock cuts was the sole source of pumping. This fact would tend to indicate that specific measures are necessary, in such instances, in order to prevent pumping. (p. 47)

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the analysis of the data obtained for this investigation.

1. For adverse conditions of soil and moisture, 20 axles over seven tons daily will produce pumping.
2. CBR values can be duplicated for soils with a CBR less than 10, but minimum discrepancies of from one

to three points should be anticipated for soils with a CBR above 10.

3. The absolute values of shapes of the CBR versus Penetration curves should be used rather than the "trends", in order to eliminate possible differences in interpretation.

4. In general, the CBR test compaction results in densities in excess of either field conditions or the maximum density as obtained by the Standard Proctor Test.

5. In general, the CBR value can be correlated with traffic and the susceptibility of a soil to pump. The theory in paragraph 11 of the "Summary" of the Analysis of Results is preferable from a design viewpoint due to high degree of accuracy for soils with a <u>maximum</u> CBR of less than 5, and those with a <u>minimum</u> CBR of 17 or greater.

6. There is no dependable relation between any of the routine physical soil tests and pumping.

7. Poor surface drainage is responsible, to some degree, for the pumping performance of a soil or soil area.

8. Subgrades containing more than 55 per cent retained on the No. 270 sieve (.05 mm.) can and do pump if the gradation is poor, particularly as reflected by its "sorting" value. Such a gradation usually incorporates large (2 inch) sized material with an excessively high percentage of clay (more than 20 per cent).

9. Soils having low clay contents and/or high silt contents are above the average in resistance to pumping.

10. In general, with regard to pumping, the performance of a residual soil will be inferior to that of transported soils. Notable exceptions are the soils derived from the Pottsville (Pennsylvanian) and the Trenton (Ordovician) geologic formations. Particularly poor performance is to be expected from soils derived from formations of the Leichfield (Pennsylvanian), St. Louis and undifferentiated Meramec (Mississippian), the Silurian, the Devonian, and Richmond, Maysville, Eden, and Cynthiana (Ordovician).

11. Special consideration should be given to the design and construction through cut sections, particularly where rock excavation is required. Adequate surface and sub-surface drainage is especially important with respect to elimination of pumping. Rigid adherence should be required for the provisions of Section 2.5.2, p. 72, of the 1945 Standard Specifications.

12. For locations where, during the life of the pavement, traffic might be expected to rise well above the value of 250 seven-ton axle loads daily, some measure should be taken to prevent pumping.

13. The following criterion is recommended for use in design of rigid pavements with regard to pumping.*

a. Measures to prevent pumping should be required if:

(1) The <u>maximum</u> CBR value is 5 or lower and the anticipated traffic is greater than 20 seven-ton axle loads daily.

(2) The <u>maximum</u> CBR value is between 6 and 10, inclusive, and the anticipated traffic is greater than 50 seven-ton axle loads daily.

(3) The <u>maximum</u> CBR value is 11 or greater and the <u>minimum</u> CBR value is 16 or less, if the anticipated traffic is greater than 100 seven-ton axle loads daily.

b. For traffic up to 250 seven-ton axle loads daily, measures to prevent pumping should not be required if:

(1) The <u>minimum</u> CBR is 17 or greater.

(2) There is 15 or lower percentage of clay in the soil <u>regardless of the CBR</u>.

c. Where there is no reasonable doubt that the soil was derived from one of the following groups of geologic formations, the following, within the limits set, should supplant the provisions of part (a) and (b) above:

*Traffic values are for two directions for two lane pavement. For four lane pavement, traffic in one direction should be considered.

(1) Measures to prevent pumping should be required if the anticipated traffic is greater than 20 seven-ton axle loads daily for soils of the:

(a) St. Louis Limestone (Mississippian)
(b) Richmond (Ordovician)
(c) Maysville (Ordovician)
(d) Cynthiana (Ordovician)
(e) Eden (Ordovician)

(2) Measures to prevent pumping should not be required for the:

(a) Pottsville (Pennsylvanian) if the clay content is 20 per cent or less for traffic up to 200 seven-ton axle loads daily.

(b) Trenton (Ordovician) for traffic up to 250 seven-ton axle loads daily.

d. If a granular base course is used in the design against pumping, it should consist of a material with a minimum CBR of 20, and should contain less than 15 per cent clay (finer than .005 mm.).

e. Specific measures should be taken to prevent water from being trapped in the subgrade where excavations through rock are necessary. Furthermore, rigid adherence should be required for the provisions of Section 2.5.2, p. 72, of the 1945 Standard Specifications, with regard to construction through cut sections in earthwork.

f. Soils with <u>minimum</u> and <u>maximum</u> CBR values of a "borderline" nature should be considered carefully. If a change in CBR of one or two points, particularly for values of ten or above, would mean the difference in designing or not designing against pumping, a duplicate test should be run and the lower of the two values used.

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